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(54) Semiconductor Hetero-Junction Element

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SPECIFICATION

1. Title of the Invention Semiconductor Hetero-Junction Element

2. Claims

1. A semiconductor hetero-junction element characterized in that a single hetero-junction is formed by $Al_xGa_{1-x}N$ ($0 \le x \le 1$), which is an n-type Group III-V compound semiconductor, and $Al_yGa_{1-y}N$ ($0 < y \le 1$), which is a p-type Group III-V compound semiconductor, provided thereon.

2. A semiconductor hetero-junction element characterized in that a double hetero-junction is formed by an n^+-type $Al_xGa_{1-x}N$ ($0 < x \le 1$) film, an n- or p-type $Al_yGa_{1-y}N$ ($0 < y \le 1$, $x > y$) film provided thereon, and a p^+-type $Al_xGa_{1-x}N$ ($0 < x \le 1$) film provided on the n- or p-type $Al_yGa_{1-y}N$ film, or by a p^+-type $Al_xGa_{1-x}N$ ($0 < x \le 1$) film, an n- or p-type $Al_yGa_{1-y}N$ ($0 < y \le 1$, $x > y$) film provided thereon, and an n^+-type $Al_xGa_{1-x}N$ ($0 < x \le 1$) film provided on the n- or p-type $Al_yGa_{1-y}N$ film.

3. Detailed Description of the Invention

The present invention relates to a hetero-junction element of a Group III-V compound semiconductor having a wide bandgap (energy gap Eg > 2.5 eV) such as GaN, AlN, or $Al_xGa_{1-x}N$ ($0 < x < 1$).

Conventionally, Group II-VI compound semiconductors such as ZnS and ZnSe, Group III-V compound semiconductors such as GaN, and Group IV-IV compound semiconductors such as

SiC are used as materials of a light-emitting element which emits visible light of a blue region. When a Group II-VI compound semiconductor such as ZnS is used, not only is growing a good single-crystal substrate difficult, but control of a surface and an interface is also difficult. Furthermore, a p-type epitaxial film (hereinafter referred to as "epi-film") thereof cannot be grown, due to self-compensation effect in relation to impurity doping. Therefore, when a light-emitting element is formed, the element must have an MIS structure. The MIS structure is formed by using, for example, n-type ZnS as a semiconductor region (S), ZnO as an insulating region (I), and Au as a metallic region (M). However, the resultant light-emitting element has drawbacks including high operation voltage and low emission intensity, and therefore, a light-emitting element of high efficiency cannot be produced.

When not doped with an impurity, a GaN material is usually of n-type due to vacancy of N, but doping with an acceptor dopant such as Zn or Mg only elevates resistance of GaN, failing to form a p-type epi-film. Thus, also in the case of GaN, the resultant light-emitting element usually has an MIS structure. For example, when an "S" layer is formed from non-doped GaN, an "I" layer is formed from Zn-doped GaN, and "M" is formed from In to thereby form MIS, the resultant light-emitting element has a drawback; i.e., the operation voltage of the element is as high as 7.5-10 V. An SiC material, typically doped with Al serving as an acceptor and

N serving as a donor, is capable of forming a pn-junction, with some shortcomings; i.e., control of the crystalline polymorphism is difficult and emission efficiency is low due to the emission mechanism being attributed to indirect transmission between bands.

In an attempt to solve the aforementioned drawbacks, the present inventors, noting that AlN and $Al_xGa_{1-x}N$ ($0 < x < 1$) can each become of p- and n-type and that these materials have high lattice matching with GaN, have formed a hetero-junction element by use of GaN and $Al_xGa_{1-x}N$ ($0 < x \leq 1$). Accordingly, an object of the present invention is to provide a light-emitting element which emits light at high efficiency in a visible light region in the vicinity of a blue region.

Fig. 1 is a graph showing the dependency, on composition x, of the lattice constant and optical absorption edge of $Al_xGa_{1-x}N$ ($0 \leq x \leq 1$) which is used for designing the hetero-junction element of the present invention, and the dependency, on composition y, of the lattice constant and optical absorption edge of $Al_yGa_{1-y}N$ ($0 \leq y \leq 1$) which is also used for designing the hetero-junction element of the present invention. In Fig. 1, reference numeral 1 denotes the composition-dependency of a lattice constant, and reference numeral 2 denotes the composition-dependency of an optical absorption edge.

For example, when the composition y of an active layer $Al_yGa_{1-y}N$ ($0 \leq y \leq 1$) is set at 0.2, in order to attain a degree of lattice mismatch in hetero-junction formation

between the active layer and $Al_xGa_{1-x}N$ ($0 < x \leq 1$, $x > y$) of 0.2% or less, the lattice constant (5.13 Å) at $y = 0.2$ is first read out from the graph of Fig. 1, then the lattice constant at which the degree of lattice mismatch is 0.2% or less (a range of 5.12 Å to 5.13 Å) is obtained, and next the composition x ($0.20 < x < 0.25$) is determined.

Production of the element of the present invention will be described by way of the following examples.

Example 1

Fig. 2 is a cross-sectional side view of an example of a single hetero-junction element formed on an insulating substrate. Reference numeral 3 denotes an insulating substrate, 4 denotes an n-type GaN or n-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$) film, 5 denotes an ohmic electrode, and 6 denotes a p-type $Al_yGa_{1-y}N$ ($0 < y \leq 1$) film. The insulating substrate is a C-plane sapphire substrate, an R-plane sapphire substrate, an SiC substrate, or an AlN substrate. The n-type GaN film is formed to have a thickness of several μm through vapor phase epitaxy. As the vapor phase epitaxy, there is employed a method in which N_2 is used as a carrier gas, metallic Ga is reacted with HCl to thereby form $GaCl_3$, which is a chloride of Ga, and $GaCl_3$ and NH_3 gas are subjected to thermal decomposition reaction, to thereby grow a GaN epi-film, or a method in which N_2 or H_2 is used as a carrier gas, and NH_3 gas and an organometallic compound such as $(CH_3)_3Ga$ are subjected to thermal decomposition reaction, to thereby grow a GaN epi-film. In the case of the former method, the temperature of

the substrate is set at 1,000-1,100°C, whereas in the case of the latter method, the temperature of the substrate is set at an appropriate temperature equal to or lower than 700°C. Usually, the thus-formed non-doped GaN epi-film becomes an n-type film due to the effect of N-vacancy, and has a carrier concentration of 10^{18-20} cm^{-3}. The GaN film *per se*, without being doped with a specific donor, is used as an n-type epi-film. Growth of the n-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$) epi-film is carried out through the aforementioned n-type GaN vapor phase epitaxy by use of $AlCl_3$ serving as a chloride or $(CH_3)_3Al$ serving as an organometallic compound. The n-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$) is doped with Si serving as a donor by use of, for example, an SiH_4 gas. The composition x is determined by controlling the ratio of gas flow rates in relation to Al and Ga. Similar to the case of the aforementioned n-type film, the p-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$) epi-film is formed by doping with an Al substituent such as Be, Mg, or Zn or an N substituent such as C, serving as an acceptor, through vapor phase epitaxy, and deposited on the n-type epi-film, to thereby form a hetero-junction. As shown in Fig. 2, the ohmic electrode of metallic In is provided, through vacuum deposition, on the p-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$) and the n-type GaN, or the n-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$).

In order to operate the single hetero-junction element, as shown in Fig. 2, the + polarity of a direct-current voltage is applied to the electrode formed on the p-type film, and the - polarity of the voltage is applied to the electrode

formed on the n-type film and to induce emission of light.. The voltage to be applied, which can be determined on the basis of the energy corresponding to the wavelength of blue light emission (i.e., about 2.5 eV or more), is set to fall at 2.5-3 V, which is 1/3 to 1/4 the voltage applied to a light-emitting element having a conventional MIS structure. The current is 10-100 mA.

Example 2

Fig. 3 is a cross-sectional side view of an example of a single hetero-junction element formed on a conductive substrate. Reference numeral 7 denotes a conductive substrate, 8 denotes an ohmic electrode formed on the conductive substrate, and 4, 5, and 6 denote the n-type GaN or n-type $Al_xGa_{1-x}N$ $(0 < x \leq 1)$ film, the ohmic electrode, and the p-type $Al_yGa_{1-y}N$ $(0 < y \leq 1)$ film, respectively, which are described in Example 1. An n-type Si substrate having a conductivity of several ohms/cm is used as the conductive substrate. On the conductive substrate, n-type GaN or n-type $Al_xGa_{1-x}N$ $(0 < x \leq 1)$ epi-film is grown through the method as described in Example 1. On the thus-formed n-type film, p-type $Al_yGa_{1-y}N$ $(0 < y \leq 1)$ epi-film is grown so as to attain the same thickness as described in Example 1, to thereby form a hetero-junction. In a manner similar to that described in Example 1, an ohmic electrode of metallic In is formed on the epi-film through vacuum deposition. An ohmic electrode of Au is formed on the conductive substrate through vacuum deposition.

In order to operate the signal hetero-junction element, in a manner similar that described in Example 1, a voltage of 2.5-3 V is applied to the element so as to attain the polarities shown in Fig. 3 and to induce emission of light.

Example 3

Fig. 4 is a cross-sectional side view of an example of a double hetero-junction element formed on an insulating substrate such as sapphire. Reference numerals 3 and 5 denote an insulating substrate and an ohmic electrode, respectively, which are described in Example 1. Reference numeral 9 denotes n^+-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$), 10 denotes n^+-type $Al_{x'}Ga_{1-x'}N$ ($0 < x' \leq 1$, $x' > x$), 11 denotes n-type or p-type $Al_yGa_{1-y}N$ ($0 < y \leq 1$, $x' > y$), and 12 denotes p^+-type $Al_{x'}Ga_{1-x'}N$ ($0 < x' \leq 1$). On the insulating substrate 3, the n^+-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$) is grown in a manner similar to that described in Example 1, so as to attain a thickness of several μm. In order to render the film to assume n^+-type, the amount of the donor employed is greater than that used for forming an n-type film. On the thus-formed n^+-type $Al_xGa_{1-x}N$, n^+-type $Al_{x'}Ga_{1-x'}N$ ($0 < x' \leq 1$, $x' > x$) is grown so as to attain a thickness of about 0.4-1 μm. On the n^+-type $Al_{x'}Ga_{1-x'}N$, n-type or p-type $Al_yGa_{1-y}N$ ($0 < y \leq 1$, $x' > y$) serving as an active layer is grown so as to attain a thickness of about 0.1-0.4 μm. The values of the compositions x' and y are set by use of the graph of Fig. 1, so that the degree of lattice mismatch falls in a range of ~0.1% or thereabouts. On the active layer, p^+-type $Al_{x'}Ga_{1-x'}N$ ($0 < x' \leq 1$) is grown so as to

attain a thickness of about 0.4-1 μm. In order to render the film to assume p^+-type, the amount of the acceptor mentioned in Example 1 is increased as compared to the case in which p-type film is formed. As shown in Fig. 4, the In ohmic electrode 5 is formed on the p^+-type $Al_{x'}Ga_{1-x'}N$ layer 12 and the n^+-type $Al_xGa_{1-x}N$ layer 9 through vacuum deposition. In Example 3, the layers 9 and 10 are of n^+-type, and the layer 12 is of p^+-type. However, the layers 9 and 10 may be of p^+-type, and the layer 12 may be of n^+-type.

In order to operate the thus-formed double hetero-junction element, as shown in Fig. 4, the + polarity of a direct-current voltage is applied to the electrode formed on the p-type film, and the - polarity of the voltage is applied to the electrode formed on the n-type film, to thereby induce emission of light. In this case, since the refractive index of the active layer is greater than that of the respective adjacent layers, the active layer becomes a waveguide, and light is transmitted therethrough. The application voltage is reduced as compared with the case of the aforementioned single hetero-junction element, because of carrier confinement effect.

Example 4

Fig. 5 is a cross-sectional side view of an example of a double hetero-junction element having a stripe structure formed on a conductive substrate. Reference numerals 7 and 8 denote a conductive substrate and an electrode formed on the conductive substrate, respectively, which are described in

Example 2. Reference numerals 9, 10, 11, and 12 denote n^+-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$), n^+-type $Al_{x'}Ga_{1-x'}N$ ($0 < x' \leq 1$, $x' > x$), n-type or p-type $Al_yGa_{1-y}N$ ($0 < y \leq 1$, $x' > y$), and p^+-type $Al_{x'}Ga_{1-x'}N$ ($0 < x' \leq 1$), respectively, which are described in Example 3. Reference numeral 13 denotes an SiO_2 insulating layer, and reference numeral 5 denotes an ohmic electrode. On the conductive substrate, the epi-film layers 9, 10, 11, and 12 are formed in a manner similar to that described in Example 3. On the layer 12, SiO_2 film serving as an insulating layer is formed through sputtering so as to attain a thickness of 0.15-0.3 μm. The width of the stripes (grooves) is about 5-30 μm. The ohmic electrodes 5 and 8 are formed as shown in Fig. 5. As described in Example 3, the layers 9 and 10 may be formed to assume p^+-type, and the layer 12 may be formed to assume n^+-type.

In order to operate the double hetero-junction element, in a manner similar to that described in Example 3, a direct-current voltage is applied to the element so as to attain the polarities shown in Fig. 5 and to induce emission of light.

In any of Examples 1 through 4, $Al_{x'}Ga_{1-x'}N$ ($x' \neq x$, $0 < x' < x$) serving as a buffer layer may be provided, in order to reduce strain attributed to lattice mismatch between the insulating substrate or the conductive substrate and the GaN or the $Al_xGa_{1-x}N$ ($0 < x \leq 1$).

As described above, since the semiconductor hetero-junction element of the present invention includes a hetero-junction serving as a light-emitting element structure, the

element has advantages that operation voltage is low and light can be emitted at high efficiency, as compared with an element having an MIS structure. Also, since $Al_xGa_{1-x}N$ ($0 \leq x \leq 1$) is of direct transition type, high efficiency is advantageously attained as compared with the case in which SiC of indirect transition type is employed. Moreover, when the element of the present invention is formed to have a double hetero-junction element structure, light confinement effect is enhanced, and further enhancement of efficiency can be advantageously attained. Furthermore, when growth of epi-film is carried out by means of organometallic vapor phase epitaxy, from the economical viewpoints, inexpensive elements can be advantageously supplied, since production of elements can be carried out at low temperature and can thus be easily controlled, and mass-productivity is high.

4. Brief Description of the Drawings

Fig. 1 shows the composition dependency of the lattice constant and optical absorption edge of $Al_xGa_{1-x}N$ ($0 \leq x \leq 1$), and the composition dependency of the lattice constant and optical absorption edge of $Al_yGa_{1-y}N$ ($0 \leq y \leq 1$);

Fig. 2 is a cross-sectional side view of the single hetero element of the present invention formed on an insulating substrate;

Fig. 3 is a cross-sectional side view of the single hetero element of the present invention formed on a conductive substrate;

Fig. 4 is a cross-sectional side view of the double

hetero element of the present invention formed on an insulating substrate; and

Fig. 5 is a cross-sectional side view of the double hetero element having a stripe structure of the present invention formed on a conductive substrate.

1. Line showing dependency of lattice constant on composition

2. Line showing dependency of optical absorption edge on composition

3. Insulating substrate

4. n-type GaN or n-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$) film

5. Ohmic electrode

6. p-type $Al_yGa_{1-y}N$ ($0 < y \leq 1$) film

7. Conductive substrate

8. Ohmic electrode formed on the substrate

9. n^+-type $Al_xGa_{1-x}N$ ($0 < x \leq 1$) film

10. n^+-type $Al_{x'}Ga_{1-x'}N$ ($0 < x' \leq 1$, $x' > x$) film

11. n-type or p-type $Al_yGa_{1-y}N$ ($0 < y \leq 1$, $x' > y$) film

12. p^+-type $Al_{x'}Ga_{1-x'}N$ ($0 < x' \leq 1$) film

13. SiO_2 insulating layer

Drawings

Fig. 1

(1) Lattice constant (C axis, Å)

(2) Optical absorption edge (eV)

(3) Composition x ($Al_xGa_{1-x}N$)
or Composition y ($Al_yGa_{1-y}N$)

Fig. 2

Fig. 3

Fig. 4

Fig. 5